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# Distribution and abundance of bottlenose dolphins (*Tursiops truncatus*) on the south coast of Portugal

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## Resumo

Os cetáceos têm uma distribuição mundial, sendo encontrados nas zonas polares, tropicais e temperadas. Para além de habitarem zonas costeiras e *offshore*, podem também ser vistos em zonas estuarinas e rios, como é o caso do golfinho do rio Amazonas (*Inia geoffrensis*).

No passado, o Homem caçou exaustivamente diversas espécies de cetáceos para obter a sua carne e óleo. Esta caça não regulamentada, levou a que muitas espécies sofressem um decréscimo acentuado no seu número populacional, o que os colocou no limiar de extinção. Atualmente a caça ainda é permitida, contudo está sujeite a uma legislação específica. O Japão, a Noruega, as ilhas Faroé e a Islândia são os principais responsáveis pela maioria da caça e mortes de cetáceos.

O crescimento da população humana incitou o aumento das ameaças à vida selvagem, como por exemplo a sobre-exploração dos stocks pesqueiros, alterações climáticas, poluição sonora e química e *bycatch* em redes de pesca. Devido à natureza carismática destas espécies, o interesse do Homem tem vindo a aumentar de ano para ano. Consequentemente, originou um aumento do interesse na indústria de observação de cetáceos no seu habitat natural. Este tipo de atividade traz bastantes benefícios à comunidade científica, no entanto, se não for realizada adequadamente pode exercer efeitos negativos sobre o comportamento das populações observadas, diminuindo assim o seu *fitness*.

Para que se possa avaliar o estado em que as populações se encontram e o potencial impacto das atividades antropogénicas é essencial obter dados detalhados sobre a população em estudo, como por exemplo a sua distribuição e abundância. Estas informações também irão permitir que os planos de conservação sejam executados corretamente e de acordo com as necessidades da espécie ou população. Todavia, determinar estes parâmetros não é fácil, dado que os cetáceos passam a maioria do seu tempo debaixo de água e durante os avistamentos não se consegue observar a população por inteiro.

De modo a tentar obter estimativas realísticas dos vários parâmetros demográficos, diversos investigadores têm vindo a usar o método de foto-identificação. Este método é considerado não invasivo, com custos bastante reduzidos e muito útil no estudo de espécies ameaçadas. A foto-identificação baseia-se na captura fotográfica da barbatana dorsal, no caso de golfinhos, ou da parte inferior da barbatana caudal, no caso de baleias. A captura fotográfica visa documentar todas as marcas identificativas que o indivíduo possa ter.

Durante o processo de foto-identificação, as fotografias são qualificadas de acordo com o seu grau de qualidade e posteriormente são criados catálogos. Estes incluem a informação das capturas e recapturas e a respetiva fotografia dos diferentes indivíduos que constituem a população em estudo. A informação que advém deste método é usada em modelos de captura-recaptura, que permitem a determinação de diferentes parâmetros demográficos, como por exemplo o tamanho da população.

Os modelos de captura-recaptura podem ser divididos em dois tipos, modelos de população fechada, que assumem que a população é constante não estando subjacente a qualquer tipo de processo demográfico (i.e. natalidade, mortalidade, emigração e imigração), ou modelos de população aberta, onde as populações poderão sofrer entradas e saídas.

Estudos com estes modelos são usados mundialmente em diferentes espécies, sendo o golfinho roaz (*Tursiops truncatus)* uma das espécies mais estudadas. O golfinho roaz é uma espécie cosmopolita, que habita em zonas tropicais e em zonas temperadas. Devido à sua plasticidade ecológica, esta espécie pode ser encontrada em vários ambientes marinhos, como zonas costeiras, zona *offshore* e estuários. A sua proximidade à costa faz com que esta espécie possa estar sujeite a uma elevada pressão antropogénica, pondo assim em causa o uso do habitat e a sua sobrevivência.

De acordo com a IUCN, o estatuto do golfinho roaz é considerado como "pouco preocupante". Contudo esta espécie é protegida por diversas jurisdições, estando listada no Anexo II da Diretiva de Habitats da União Europeia e no Apêndice II da CITES. Na Península Ibérica, esta espécie está presente ao longo de toda a costa Atlântica com populações residentes na Galiza (Espanha) e no estuário do Sado (Portugal). Porém, também existem registos de avistamentos desta espécie na costa sul de Portugal. No entanto, informação adicional sobre esta possível população ainda é escassa.

Este estudo teve como objetivo principal determinar a distribuição e alguns parâmetros populacionais chave, nomeadamente a abundância e a fidelidade ao local da espécie *Tursiops truncatus*, golfinho roaz, na costa sul de Portugal. A recolha de dados decorreu entre os anos de 2009 e 2016, maioritariamente entre os meses de Maio e Outubro, no sul da costa Portuguesa, com maior incidência em Albufeira e Sagres. Os dados foram recolhidos através de plataformas de oportunidade e de uma embarcação especializada em investigação marinha. Com os dados obtidos através do GPS foi possível determinar a distribuição dos indivíduos. As fotografias recolhidas durante o estudo foram analisadas, sendo qualificadas de acordo com o seu grau de qualidade, tendo em conta o foco, tamanho, orientação, exposição e percentagem de barbatana visível na fotografia. Posteriormente, as fotografias foram comparadas com um catálogo já existente. Quando um indivíduo não estava presente no catálogo, este era considerado como novo e adicionado ao mesmo. Através desta informação determinou-se a fidelidade que existe entre os indivíduos observados e o local de estudo, através de taxas de captura e taxas mensais de observação, e a abundância. Esta última foi estimada através de três modelos de população fechada ($M_0$, $M_t$ e $M_h$) e o modelo de população aberta, Jolly-Seber. O modelo de população aberta, Cormack-Jolly-Seber, foi utilizado para determinar a aparente probabilidade de sobrevivência e a probabilidade de recaptura.

A distribuição dos indivíduos identificados, durante o período de estudo, concentrou-se perto da costa, com uma maior incidência na zona de Albufeira. A elevada presença de indivíduos em toda a área de estudo pode ser explicada pela presença de diversos canhões submarinos. Estes são considerados locais de atração para os cetáceos devido à elevada abundância de presas existentes.

Relativamente ao parâmetro de fidelidade, a maioria dos indivíduos apresentou baixa fidelidade para com o local de estudo, indicando que serão apenas visitantes ocasionais ou que a área em estudo é um local de passagem. Estes resultados são esperados quando a população alvo é considerada uma população costeira, sendo o caso da população em estudo. Neste estudo quando o termo de população é referido, remete-se aos indivíduos que estão presentes na área de estudo (costa sul Portuguesa). As populações que habitam em ambientes estuarinos já apresentam valores de fidelidade mais elevados. A abundância destas populações nunca chega a ser de grandes dimensões. Por outro lado, as populações costeiras, tendem a ter um número populacional maior. A estimativa do tamanho da população, em estudo, feita por ambos os modelos, fechados e abertos, teve flutuações ao longo dos anos, sendo os anos de 2012 e 2013 com os valores registados mais baixos. Contudo entre ambos existiram algumas diferenças nos valores estimados.

Através dos modelos fechados, o pico do tamanho da população é atingido em 2011 enquanto que no modelo aberto, esse pico ocorre no ano de 2009. No último ano do estudo, 2016, é estimado que a população seja constituída por 237 indivíduos, através do modelo fechado $M_h$ (o que se adequou melhor aos dados), ou 439 indivíduos, através do modelo aberto Jolly-Seber. Diversos estudos estimaram o tamanho populacional em diversos locais da Europa, obtendo um máximo de 350 indivíduos na população que existe em Espanha. Comparando este resultado com o resultado obtido no presente estudo, é possível afirmar que a população deste estudo será uma das maiores da Europa.

Ambos os modelos de população aberta, Cormack-Jolly-Seber e Jolly-Seber, estimam que a sobrevivência aparente e a sobrevivência dos indivíduos é alta, respetivamente. Os níveis altos poderão significar que os indivíduos observados durante o período de estudo apresentam um bom *fitness* para com o local. A probabilidade de recaptura, estimada pelo modelo Cormack-Jolly-Seber, e a probabilidade de captura, estimada pelo modelo Jolly-Seber, ambas apresentam valores baixos. Tal poderá significar que o "*home range"* dos indivíduos pode ir além da zona amostrada. Pode concluir-se que, a população presente no sul da costa Portuguesa é uma população aberta, de grandes dimensões, onde os indivíduos utilizam a área de estudo ocasionalmente. Por último, é importante referir que esta dissertação pode funcionar como informação base de modo a que estudos futuros permitam elaborar medidas de conservação fidedignas. Em estudos futuros, seria interessante, por exemplo, incluir os meses de inverno no período de amostragem de modo a determinar a residência e perceber se de facto as diversas plataformas de observação de cetáceos têm algum impacto no comportamento dos golfinhos roazes. Seria igualmente interessante, devido à sociedade dinâmica do golfinho roaz, avaliar a estrutura social e associações entre indivíduos. Também seria de interesse, comparar o catálogo obtido nesta dissertação com outros catálogos já existentes, de modo a obter uma visão geral dos movimentos dos golfinhos roazes presentes na costa sul Portuguesa.

**Palavras-chave:** foto-identificação, modelos captura-recaptura, golfinho roaz, Portugal.

## Abstract

In the last decades, human population growth brought several different threats to marine wildlife, and to assess the health of affected populations it is critical to obtain baseline knowledge on species abundance and distribution. The Photo-ID method is used worldwide, and its application is especially common in cetacean populations, to estimated different demographic parameters through capture-recapture models (namely close and open-population models). Within this context, the present dissertation aimed to determine the population distribution, site fidelity and abundance of the bottlenose dolphin (*Tursiops truncatus*) in the Portuguese south coast, between 2009 to 2016. The data was collected in dolphin-watching boats and by opportunistic encounters and in the last years, 2015 and 2016, it was also collected with a specially-dedicated vessel. Here I show that bottlenose dolphins' distribution in the Portuguese south coast was concentrated close to shore, with a special incidence in Albufeira area. Moreover, it was possible to observe a certain number of newborns and calves, and sexual interactions, which suggest that the dolphins use the study area as a breeding and nursery area. Because in each year of the survey, newly individuals were always identified one can argue that we are in the presence of and open population. The identified bottlenose dolphins also revealed low values of site fidelity, i.e., the studied area worked as local of passage or migratory route. The abundance of individuals was never constant through the sampling years, according to both closed an open population models. Both type of models estimated the lower population sizes in the years 2012 and 2013. Yet, such models also showed big discrepancies in the population size in some years. With the two open-population models, Cormack-Jolly-Seber and Jolly-Seber, the values of apparent survival and survival, respectively, where high demonstrating that the observed individuals show a good fitness to the environment. Moreover, recapture probability under the Cormack-Jolly-Seber model, and capture probabilities under the Jolly-Seber model, were both low suggesting that individuals' home range has a much larger extension than the surveyed area. The probability of entering new individuals to the population was never very high. Summing up, this dissertation aimed to contribute to an advance on the knowledge of bottlenose dolphins' population in south of Portugal. In future studies, it would be interesting, for example, to extend the survey periods to the winter months, to fully assess residency and to try to fully understand if the individuals are suffering from the increase of dolphin-watching industry. Also, due to fission-fusion social characteristic of bottlenose dolphins, it would be interesting to evaluate the social structure and associations between individuals. A comparison between the catalogue obtained in the present dissertation and others bottlenose dolphins catalogues, is also needed, to acquire a general view of the movements of the bottlenose dolphins' present in the south coast of Portugal.



**Key-words:** photo-identification, capture-recapture models, bottlenose dolphins, Portugal.

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# 1. Introduction

## 1.1 Cetaceans

Cetaceans inhabit all the world's oceans, in coastal and open waters. For instance, in polar regions (i.e. belugas, *Delphinapterus leucas*, (Kendall and Cornick 2016), killer whales, *Orcinus orca*, and narwhals, *Monodon monoceros*, (Breed *et al.* 2017)), in tropical regions (i.e. Cuvier's beaked whale, *Ziphius cavirostris*, (Pinedo *et al.* 2001)), and in temperate regions (i.e. sperm whales, *Physeter macrocephalus*, (Aïssi *et al.* 2014)). Also, due to migration routes, a single individual can travel thousands of kilometers and occupy multiple different habitats. Humpback whales (*Megaptera novaeangliae*), for example, perform the biggest migrations among all marine mammals (Hazevoet *et al.* 2011), moving from polar to tropical regions, and vice-versa.

The cetaceans can also be found in estuaries and a few species inhabit freshwater rivers, such as the Amazon river dolphin (*Inia geoffrensis*) (Vidal *et al.* 1997). In the past, humans vigorously hunted cetaceans for their meat, blubber and oil, with no control (Parsons and Monaghan-Brown 2017). This overexploitation resulted in numerous species suffering from drastic population declines, with a significant percentage now threatened with extinction. For example, according to Ryan *et al.* (2014) the population of humpback whales present in Cape Verde had about 5000 individuals before the whaling period, and nowadays, due to overexploitation the population has decreased by 95%, is estimate that exists only 260 individuals.

Nowadays, whaling is still permitted but under a specific legislation. Different from the past, today the marine mammals are hunt for scientific (Côté and Favaro 2016) or captive display purposes. Japan (Fisher 2016), Norway (Tiili and Ramakers 2017), Faroe Islands (Singleton and Fielding 2017) and Iceland (Bertulli *et al.* 2014) are responsible for the majority of hunt.

The human population growth has also brought more threats to wildlife, such as the overexploitation of prey resources, the effects of climate change, chemical and noise pollution (Hammond *et al.* 2013), bycatch in fishing gear and ship-strikes (Fruet *et al.* 2011; Hammond *et al.* 2013; Alava *et al.* 2017). Also, due to the charismatic nature of cetaceans, the interest of the human population towards these species has been increasing. This exponential increase in interest has caused a growth in the whale-watching industry (New *et al.* 2015; Parsons and Monaghan-Brown 2017; Wakamatsu *et al.* 2017). Some studies have tried to assess if this increase in the number of whale-watching boats has an impact on cetacean populations in terms of behavioral and ecological disturbances. Parsons (2012) and Christiansen and Lusseau (2013) refer that whale-watching can have negative impacts on cetaceans, and they can be divided in short-term, long-term and non-visible effects. Also, Pérez-Jorge *et al.* (2016) determine, that 78% of the Indo-Pacific bottlenose dolphins (*Tursiops aduncus)* population left the study area when occur the presence of the highest numbers of boats. An issue of bigger concern, are changes in behavior (i.e. feeding, social interactions, traveling and resting) (Domit *et al.* 2016), because that can modify the fitness of the individuals (Peréz-Jorge *et al.* 2016). However, it is important to refer that whale-watching provides many potential benefits to people, to the marine environment (New *et al.* 2015) and to the scientific community (i.e. Gnone *et al.* 2011; Steckenreuter *et al.* 2012; Bertulli *et al.* 2015).

To assess the health of the affected populations, the potential impact of anthropogenic activities (Louis *et al.* 2015) and to have effective marine mammal conservation and management plans, it

is critical to obtain detailed data on the focus population, particularly knowledge of the abundance and distribution of the species (Parsons 2001; Bassos-Hull *et al.* 2013; Rogan *et al.* 2017).

However, trying to define populations or stocks of marine mammals can prove to be very difficult as the majority of animals within a population will not be sighted during surveys. Also, the individuals home range can influence the detection probability causing bias in the estimation of population size.

## 1.2 Population size through photo-identification

To produce a realistic estimate of population size and trends, scientists have been using photo-identification (Photo-ID) based on natural markings (Würsig and Jefferson 1990; Wells and Scott 1990). Photo-ID is a non-invasive, low cost method with many practical applications. It has been widely used to study the ecology of many different taxonomic groups, such as terrestrial (Würsig and Jefferson 1990) and marine mammals, reptiles and fish (Sprogis *et al.* 2016). In fact, this method has been an important aspect of research on the behavior and biology of cetaceans since the early 1970s (Hillman *et al.* 2003), including bottlenose dolphins (*Tursiops truncatus*) in North Carolina (Read *et al.* 2003), Hector's dolphin (*Cephalorhrynchus hectori*) in New Zealand (Gormley *et al.* 2005), Guiana dolphins (*Stolia guianensis*) in Brazil (Cantor *et al.* 2012) and Indian Ocean humpback dolphins (*Sousa plumbea*) in the Emirate of Abu Dhabi (López *et al.* 2017), among many other examples. The effectiveness of this method has been confirmed by double-tagging studies in which artificial tags were used as a positive control (Parsons 2001).

Dolphin photo-ID methods rely on obtaining a photograph of unique natural markings, such as nicks, notches, scars and pigmentation patterns on the dorsal fin (Tyson *et al.* 2011; Sprogis *et al.* 2016), while, the underside of the tail fluke is most useful in identifying individual whales (Andreotti *et al.* 2017). These marks have different causes but are mostly created by parasites, socialization, encounters with other species and some of them have anthropogenic origin (Bertulli *et al.* 2015). These natural markings are considered to be long-lasting and they can and have been used successfully to identify individuals and track them over time (Speakman *et al.* 2010; Tyson *et al.* 2011). Additionally, to provide a more comprehensive and accurate identification, it is important to consider the shape of the dorsal fin, shading of the fin and upper body (Würsig and Jefferson 1990; Parsons 2001), in addition to more obvious markings.

In case of the dolphins, these markings can be found especially in the thin connective tissue of the trailing edge of the dorsal fin (Würsig and Jefferson 1990; Speakman *et al.* 2010), due to their constant exposure. This is usually their most recognizable feature and therefore is frequently used for identification. These distinctive marks can be different on the left and right sides, so it is important to obtain photographs of both sides to ensure a more precise identification and reduce the chance of over or under estimated results (Evans and Hammond 2004).

During the photo-ID process, the photographs taken are matched with those in previously made catalogues or are used to create a new one. During the matching process if the individual already has been identified it is considered a recapture and if the individual has not already been catalogued, it is given a new systematic name.
The catalogue is composed only with excellent quality photographs. The quality qualification varies between investigators but the main goal of every qualification grade is to be able to identify

every mark without any doubt. The individuals acquire nicks as they get older and younger animals are typically not well marked (Evans and Hammond 2004) so juveniles and calves are not included in the catalogue (Urian *et al.* 2015).

One of the uses of photo-ID data is in mark-recapture or capture-recapture models that allow the determination of different parameters such as population size (Würsig and Jefferson 1990; Bertulli *et al.* 2015) and probability of detection (Kéry and Schaub 2012). To have an accurate estimate it is necessary to make some assumptions, for example that a mark in an animal will always be recognized over time and be unique (Würsig and Jefferson 1990; Kéry and Schaub 2012), that samples of individuals must be representative of the population being estimated, that marking an animal does not affect its probability of recapture and that every animal has the same probability of being captured (Navarro *et al.* 2014).

Studies that use photo-ID information have been used across the entire world in many different species, yet the bottlenose dolphins are one of the most studied species in the entire world (i.e. Vermeulen and Cammareri 2009; Tyson *et al.* 2011; Dinis *et al.* 2016; Laporta *et al*. 2016).

## 1.3 Capture-recapture models

Capture-recapture models in general are the most commonly used to estimate demographic parameters (Chao 2001), such as population size (Kéry and Schaub 2012) and animal survival rates (Poole 2002).

These models use repeated observations of recognizable individuals and derive information about the detection probability, *p*, from the pattern of detection and non-detection of each marked individual (Kéry and Schaub 2012).

The basic theory behind capture-recapture modeling uses the information that the number of marked animals that are recaptured in a sample will be equivalent to the proportion of marked animals in the total population (Parsons 2001; Aschettino 2010).

The capture–recapture methods have some theoretical assumptions, such as (1) all the marks of the individual are permanent and don not lead to misidentifications, (2) recapture probability not affected by its first capture, (3) the death or migration of an individual is not affected by its handling and any migration will be permanent, (4) all the animals have the same probability of being captured, being marked, that assures a random sampling, (5) all individuals, the ones that are marked and not, have the same probability of dying or emigrate, that means that the population movements are not affected by whether individuals are marked or not (Navarro *et al.* 2014)

Kéry and Schaub (2012) and Pérez-Jorge *et al.* (2016), refers that these models can be divided in two types, closed-population models, where its considered that in the sampling period don not occur population losses (emigration or death) or gains (birth or immigration), and open-population models, which are based on a multi-year sampling where is counted all the demographic process that can happen during the sampling.

### 1.3.1 Closed-population model

Closed-population models are conducted over short periods of time, where the population can be considered as "closed" to changes, assumed to be constant. When a population is assumed to be

closed it means there are no births, mortality, emigration and recruitment (Chao 2001; Speakman *et al.* 2010; Kéry and Schaub 2012).

Besides the characteristics mentioned above, this model has three more assumptions, namely: (1) animals do not lose their marks or tags, (2) all marks or tags are correctly recorded and (3) animals act independently (Chao and Huggins 2005).

The closed-population model has eight models defined, $M_0$, assumes that the imperfect detection is constant across all individuals and times, $M_h$, for individual heterogeneity, $M_t$ for time and $M_b$ for behavioral response. Other four models exist that are the combinations of effects $M_{th}$, $M_{bh}$, $M_{tb}$ and $M_{tbh}$ (Kéry and Schaub 2012).

Model $M_0$, is the simplest model for inference about the size of a single population (Kéry and Schaub 2012). In this model, the population is considered homogeneous in respect of capture probability (*p*) (Borchers *et al.* 2002), which means that all members of the population are equally likely to be captured on every trapping occasion (Otis *et al.* 1978; Navarro *et al.* 2014). This model has only one more parameter, population size (*N*), besides *p*.

Model $M_h$, assumes that each individual has its own unique capture probability and its independent of all the other members of the population (Otis *et al*. 1978). The detection probability is constant over all sampling occasions (Chao and Huggins 2005; Kéry and Schaub 2012).

Model $M_t$, refers that the probability of capture varies with time (Chao and Huggins 2005; Navarro 2014) or occasion (Kéry and Schaub 2012). In this model the parameters are *N* and probability of capture on a determined occasion (Otis *et al.* 1978).

Model $M_b$, relies on the behavioral response that an individual has after his first capture. The capture probability of unmarked animals differs from the marked animals (Otis *et al.* 1978). The individuals can be considered "trap-shy" when capture had a negative impact on its capture probability (Kéry and Schaub 2012), which means that the probability of being captured, will decrease, in the subsequent sampling occasions. They also can be classified as "trap-happy", when initial capture has a positive impact on their capture probability (Kéry and Schaub 2012), meaning that the probability of capture will increase after the first capture.

Model $M_{th}$, combines time and individual effects (Kéry and Schaub 2012). This model assumes that the capture probability of an animal is independent of its capture history and the time variation affects all members in the same way (Otis *et al.* 1978).

Model $M_{bh}$, assumes that each animal of the population has its own response to the initial capture and its unique probability of being capture (Otis *et al.* 1978).

Model $M_{tb}$, where the capture probability varies with time and by behavioral response to capture. Assume that the probability capture of an animal changes after his initial capture and the temporal changes also have effect on capture probability (Otis *et al*. 1978).

Model $M_{tbh}$, combines all the three effects, time, behavioral response and heterogeneity. The model considers that each individual has its own probability of being captured, and that probability can be modified regarding the response to initial capture, and that the capture probability changes over time (Otis *et al*. 1978).

### 1.3.2 Open-population model

Open-population models are used in samplings with a larger period of time (Speakman *et al.* 2010), where newly captured animals are individually marked and identities of previously captured animals are recorded (Nichols 2005).

In long periods of sampling, it should be considered that the population size will likely change during the study (Nichols 2005). The population can suffer gains, through births and immigration, and losses through death and emigration (Pollock 2000).

This model can be divided in two, Cormack-Jolly-Seber (CJS) and Jolly-Seber (JS) models (Pollock 2000).

CJS model can be used to estimate survival and capture probabilities. It only requires information about the recaptures of the marked animals (Pollock and Alpizar-Jara 2010).

This model as its owns assumptions that need to be validated before its use, namely: (1) every marked animal within the population during the sampling period has the same probability of being recaptured, (2) every marked animal has the same probability of survival in the next occasion of sampling and its independent of the other animals, (3) marks are not lost and recorded correctly, (4) the sampling periods are instantaneous, and (5) all the emigration is permanent (Poole 2002).

The JS model, allows estimation of population size at each sampling time as well as the inclusion of survival and birth rates between sampling occasions (Pollock *et al.* 1990)

In order to valid the model, it's necessary to have in consideration the following assumptions, (1) equal catchability for every animal alive within the population, (2) every animal alive in the population as the same probability of survival from one encounter to another, (3) the animals do not lose their marks, (4) all emigration is permanent and (5) every animal caught in one encounter has the same probability of returning to the population (Pollock *et al.* 1990; Pollock and Alpizar-Jara 2010; Aschettino 2010).

## 1.4 Bottlenose dolphins

Bottlenose dolphins (*Tursiops truncatus)* are a cosmopolitan species found in all tropical, subtropical and temperate seas (López *et al.* 2013; Giacomo and Ott 2016; Laporta *et al.* 2016; Baş *et al*. 2016; Durden *et al.* 2017), only being absent from polar waters (Pulcini *et al*. 2013). In fact, due to their distinctive behavior and ecological plasticity (Fernández *et al.* 2011; Domit *et al.* 2016), bottlenose dolphins inhabit a variety of marine environments such as ocean pelagic waters, shallow coastal areas (Fury and Harrison 2008; Gonzalvo *et al.* 2013) and estuaries (Fruet *et al.* 2011). This adaptive response to various habitats contributes to their wide distribution (Benmessaoud *et al.* 2013; López *et al.* 2013). Due to their wide distribution range, two ecotypes have been described (Tezanos-Pinto *et al.* 2009), a coastal ecotype, inhabiting open shores, bays and inland estuaries, and an offshore ecotype, residing in neritic and oceanic waters (Félix *et al.* 2017). Both ecotypes can coexist sympatrically in a few areas, the main different between them it is the morphological aspect, individuals consider as offshore have a bigger dimension and a darker color, habitat specialization and social organization and structure (Félix *et al.* 2017).

Coastal populations of bottlenose dolphins are frequently small with high levels of residency in protected estuarine habitats (Laporta *et al.* 2016). Populations inhabiting open waters, are normally larger, and exhibit a smaller degree of residency (Laporta *et al.* 2016). Residency refers to how long the individuals stay within a defined area, if they are present the entire year or if the area is only a passing or migration route (Dinis *et al.* 2016). Residency and site fidelity are two different parameters. High site fidelity, indicates that is very probable that the individual returns to the same place every year, while opposite low fidelity suggests that the individual only visits this location on occasion (Baird *et al.* 2008; Zanardo *et al.* 2016). All the above-mentioned characteristics make this species one of the most comprehensively studied cetaceans (Grellier and Wilson 2003; Pleslić *et al.* 2013), well-known by the public because of their common use in captivity (Wells 2009) and their charismatic figure.

This species is most often found in groups of up to 15 individuals (Shirihai and Jarrett 2006). The social units include nursery groups, juvenile and adult male groups (Wells 2009). They are considered opportunistic feeders (McCluskey *et al.* 2016) or generalist predators, with a diet relying on fish, krill and other crustaceans (Hernandez-Milian *et al.* 2015). They usually hunt in groups, disorienting their preys by leaping and pushing them shoreward, however some time they can take advantage of small-scale fisheries (Shirihai and Jarrett 2006). The lifespan of this species is 52 years (Augusto *et al.* 2012).

The knowledge about different demographic parameters such as population size, trends in abundance, distribution and movement patterns help to determine a thorough understanding of the boundaries of each dolphin stock (Laporta *et al.* 2016). With this data, it is possible to gain information about the habitat suitability of the surrounding environment and it is essential to monitor human impacts (Laporta *et al.* 2016) on the local population and to define decisions about conservation efforts (Martinho *et al.* 2014). Nowadays, these studies are proving to be very important in costal populations of bottlenose dolphins, due to the overlap with anthropogenic activities, such as dolphin-watching tourism (Baş *et al.* 2016).

According to the IUCN the bottlenose dolphins are classified “least concern”, however they are listed in Annex II of the European Union’s Habitats Directive (Directive 92/ 43/CEE). This requires member states to consider key locations inhabited by the species to be designated as special areas of conservation (SAC) for their protection (Silva *et al.* 2008; Martinho *et al.* 2014), reiterated by Annex IV, which states the need of strict protection for these localities (Louis *et al.* 2015). The species is also listed in Appendix II of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora). Appendix II names the species as not necessarily threatened with extinction now, but may become so unless the threats they are subject to be closely controlled.

In the Iberian Peninsula, this species is present continuously along the Atlantic coast with resident populations in southern Galicia, Spain, and in the Sado estuary, Portugal (Fernández *et al.* 2011; Martinho *et al.* 2014). In fact, the Sado estuary population is very well studied (Van Bressem *et al.* 2003; Martinho *et al.* 2014; Luís *et al.* 2014). This population is subjected to multiple threats, such as boat traffic and pollution, with numerous studies showing that the number of individuals in this population have been decreasing due to the non-existent immigration, low recruitment and aging of individuals (Augusto *et al.* 2012). However, there are also records of sightings of bottlenose dolphins on the south coast of Portugal, that indicates a possible population, but there is a significant lack of information available.

Portugal, besides being a member of European Union, is also involved in multiple initiatives that aim to protect different cetacean species, where the bottlenose dolphin is included, such as ACCOBAMS (Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contigous Atlantic Area) and IWC (International Whaling Commission).

# 2. Objectives

This study aims to determine key population parameters such as distribution, abundance and site fidelity of bottlenose dolphins (*Tursiops truncatus*) along the Portuguese south coast. These estimates will contribute to the assessment of the trend of this population in future studies, to determine the effect of anthropogenic activities and to correctly determine conservation efforts.

# 3. Materials and Methods

## 3.1 Study Area

The study was conducted in the south coast of Portugal, Algarve region, mostly in Albufeira (37°05'19.74''N, 8°14'52.84''O) and Sagres (37°00'54.90''N, 8°56'25.91''O) (Figure 3.1).


Figure 3.1 – Map of the study area, south coast of Portugal, with the main localities represented.

The coastline of Algarve is about 160 km and can be divided in two different sectors, the occidental coast (Barlavento) that is dominated by cliffs, since Cabo São Vicente to near Faro, and the oriental coast (Sotavento) with mostly sandy beaches, starting in Faro and ending near the Spanish border (Borges *et al.* 1997; Lopes and Cunha 2010).

According to Matias *et al.* (2015) the Algarve continental margin besides being part of the NE Atlantic basin, it is under a strong influence of the Mediterranean climate and oceanographical dynamics.

An important characteristic of the coast of Algarve is the presence of submarine canyons and trenches, which facilitates the flow of the water masses and sedimentary load (Lopes and Cunha 2010). The most important canyons are the Lagos, Portimão, Albufeira, Faro and São Vicente canyons. Concerning the trenches, the most important ones is the Diogo Cão and Álvares Cabral trench (Castro 2010).

## 3.2 Data collection

Surveys were carried out from 2009 to 2016, mostly between May and October. The data was collected in dolphin-watching boats and by opportunistic encounters and in the last years (2015 and 2016) it was also collected with a specially dedicated vessel. My participation in the field was in the last year of the sampling period, during three months, since July until September, where I collect data in both platforms, dolphin-watching boats and the dedicated vessel.

In each trip a Global Positioning System (GPS) was used to record every track and the exact place of the first time that the animals were spotted. When a group of bottlenose dolphins were spotted, the boat approach them and researchers start to take photographs of the dolphin's dorsal fin. During the sighting the objective was to take the highest number possible of photographs from all the individuals present and if was possible take photographs of both sides of the fin. The photographs were taken using a Nikon D200 with a 75-300 mm lens.

In the present study, the term population is used to refer the individuals that are present in the study area and not according to the ecological definition.

## 3.3 Photo-identification process

The photographs taken were compared with a catalogue already made. The individuals that weren't on the catalogue, were considered as new individuals. To the new individuals, a specific code was attributed with the form TT_ALG_XXXX, where TT stands for the scientific name of the species (*Tursiops truncatus*), ALG it means the local of the study (Algarve), and XXXX represents the number assigned to the particular individual in the catalogue. It was made a catalogue for the left side and other to the right side to decrease the possibility of having misidentifications.

The matching process was made without using a Photo-ID program. The individuals were recognized by their nicks, notches, the shape of the fin or specific pigmentation patterns. All the matching process was made by me and then rectified by a more experience researcher. Before the matching, every photograph was classified according with a quality rating (Q), on a scale from 0 to 2, poor to excellent respectively (Figure 3.2), based on five characteristics: focus, size, orientation, exposure and the percentage of the fin visible in the frame (Table 3.1). In the catalogue only enter the photographs with the best quality (Q1 and Q2). Regarding the angle of the dorsal fin, it´s consider 0° when the animal is photographed directly from the front and goes around the animal clockwise every 30° (Figure 3.3).

Table 3.1 – Description of the quality rating scale (Castro 2010).

| Quality rating (Q) | Description |
|---|---|
| **Q0** | Unusable individual dorsal fin: blurred, too far away or if the angle is between 330º and 30º or 150º and 210º |
| **Q1** | Medium quality representation of part of the fin or the entire dorsal fin |
| **Q2** | High quality representation of the entire dorsal fin |


Figure 3.2 – Pictures of different individuals, with a different quality rating, taken during the survey period. (a) photographs with quality Q0, (b) photographs with quality Q1 and (c) photographs with quality Q2.

The information of the resulting data was added to the Microsoft EXCEL datasheet of a previous catalogue (Castro 2010). This datasheet was composed with basic information such as the sighting number, picture number, number of individuals per picture, number of the individual analyzed, date of the picture, angle, individual quality and the individual name code.

When there are several individuals within a specific photo, the classification starts from the closest individual to the furthest and from left to right when the animals were at the same distance.

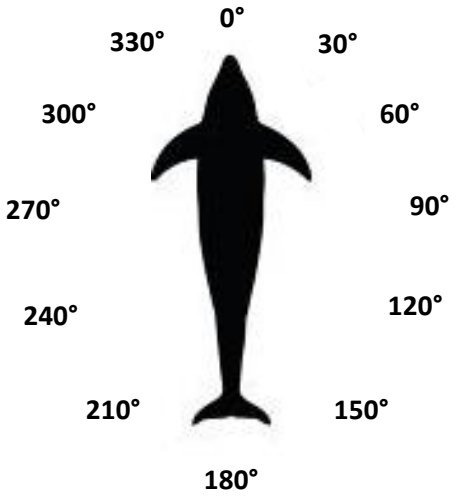


Figure 3.3 – Representation of the angles, when takin a photograph of the dolphin's dorsal fin.

## 3.4 Data analysis

3.4.1 Effort and distribution maps

The tracks and points record by the GPS were transfered to the program ArcMap 10.4.1 to have an effort and distribution maps.

3.4.2 Photo-identification

The photographic identifications and reidentifications were treated as "captures" and "recaptures" respectively. With this information, a matrix was created using a binary code, of 1 and 0, for all identifications histories in the different survey periods. The value 1 or 0 indicates if the individual was sighted or not during the sampling occasion. The matrix is composed various series of 1s and 0s, where each series represents the encounter history of a specific individual. For example, an encounter history of an animal (1100111) correspond to seven encounter occasions, after being seen two times, the individual was not seen in the next two sampling occasions, and seen again in the last three occasions.

3.4.3 Site fidelity

There are multiples ways do determine site fidelity, and the choice depends on what the researcher thinks it is more suitable for its own data and what approach they prefer (e.g. Fury and Harrison 2008; Giacomo and Ott 2016; Dinis *et al.* 2016; Zanardo *et al.* 2016). Moreover, the former study refers that it is possible to calculate this parameter by three measures, seasonal sighting rates, monthly sighting rates and capture rates. It is worth noting that in the present dissertation it was not possible to determine seasonal sighting rates because the survey only occurred during summer periods.

The site fidelity was calculated through: i) monthly sighting rates (proportion between the number of months a dolphin was sighted and the total number of months surveyed) and ii) capture rates (the ratio between the number of recaptures of each dolphin and the number of days surveyed since the first capture and the last recapture). In both site fidelity indices if the result is equal to 1, it means that the individual was capture in every month (monthly sighting rates) or every single day (capture rates) since his first capture to his last, and if the result is equal to 0, it means that the individual was never recaptured after his first capture (Zanardo *et al.* 2016).

To avoid false results, the individuals who had recaptures but only in the year of their first capture were not take into consideration in the calculation of these site fidelity indices. If these individuals were included in the calculations, the value of site fidelity for those individuals it would be higher but that does not correspond with the reality.

3.4.4 Statistical inference

Five different models were fitted to the data obtained through photo-identification. Closed-population models, namely $M_0$, $M_t$ and $M_h$, were applied in each year of the survey, individually, and open-population models, namely Cormack-Jolly-Seber and Jolly-Seber, were applied in the set of years of the survey.

The closed-populations models who include a behavioral response, were not applied in the present dissertation, because it is considered that photo identification does not cause any effects in the individuals.

To determine the best model was used the deviance information criterion (DIC) (Spiegelhalter *et al.* 2002). DIC, used in a Bayesian inference, is equivalent to Akaike's Information Criterion (AIC) in a frequentist inference. They are used to measure the goodness of fit, comparing all tested population models (Ribarič 2017). The smallest it is the DIC or ΔDIC values, the better the model fits to the data (Berg *et al.* 2004). These models were implemented within a Bayesian framework, where was consider noninformative prior distributions, Uniform (0,1). A uniform distribution indicates that the probability of a parameter can be any value between 0 and 1.The models were run in the program R (R Core Team, 2016), using the package R20penBUGS (Sturtz *et al.* 2015) and the program OpenBUGS (Lunn *et al.* 2009).

# 4. Results

## 4.1 Effort and distribution maps

Figure 4.4 illustrates all the tracks from every trip that where conducted during the survey period. Since 2009 until 2016, the total effort was 63 882 km, with the highest effort in 2014, with 12 978 km, and the lowest in 2011, with 5 720 km.

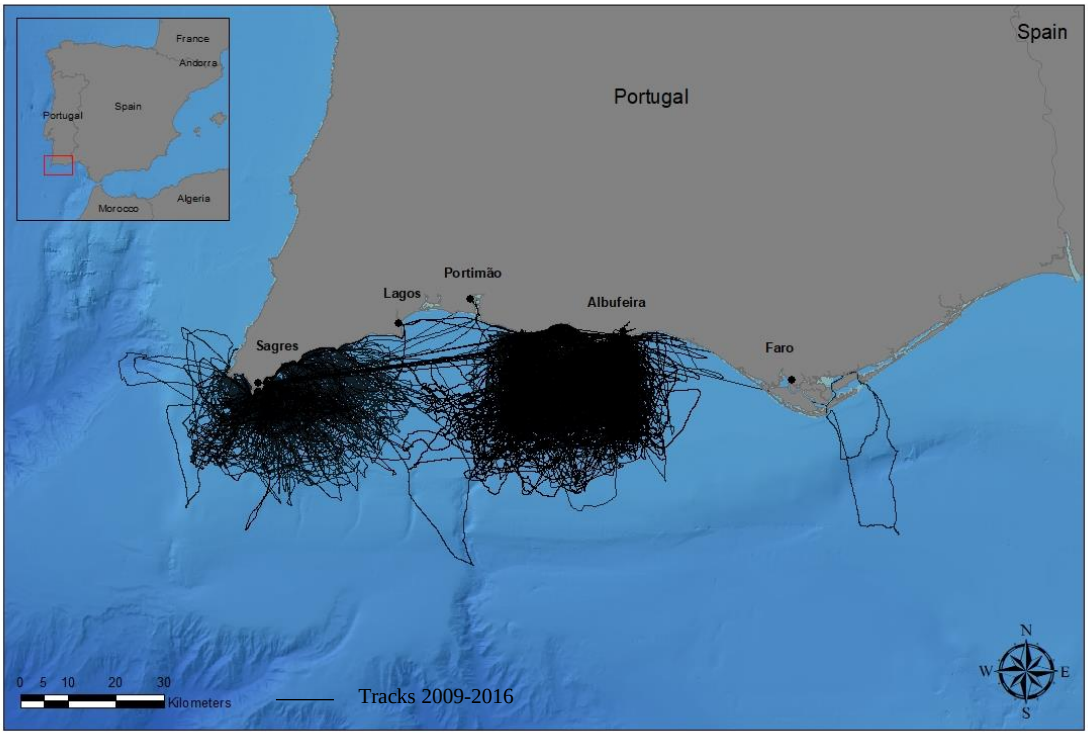


Figure 4.4 – Effort map, where the black lines represent the tracks from all the trips conducted during the survey period in the south coast of Portugal (the study area).

During the survey, 774 sightings of bottlenose dolphins were recorded. The year 2014, was the one with the maximum number of sightings, 170 sightings, and 2009 was the year with lowest one, only 20 sightings.

Figure 4.5 illustrates de distribution of the species *Tursiops truncatus*, since 2009 until 2016, in the south coast of Portugal.

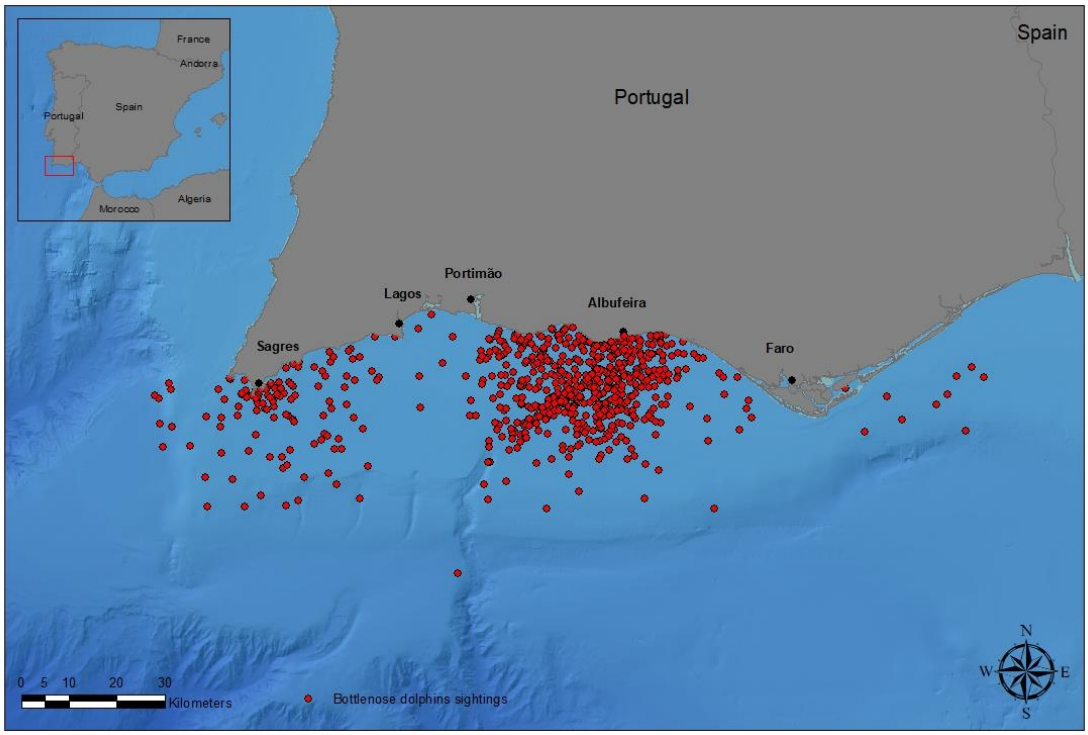


Figure 4.5 – Distribution map of bottlenose dolphins in the south coast of Portugal (the study area). The red dots represent the bottlenose dolphins' sightings during the survey period.

## 4.2 Photo-identification

From the 774 sightings occasions, it was possible to collect 68 146 photographs, but only 5 650 photographs were used in the present dissertation. From these photographs, it was possible to identify 549 individuals in total (left and right side catalogues).

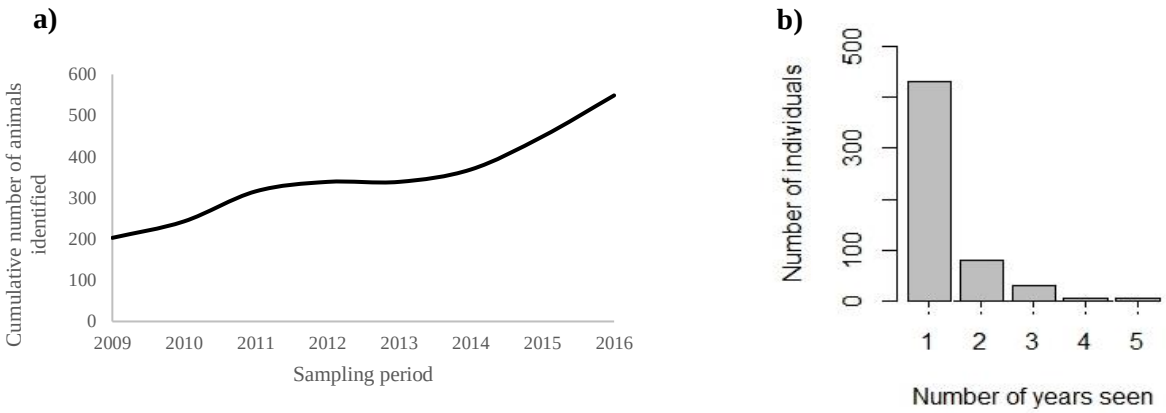


Figure 4.6 - Graphic representation of the number of individuals identified during the sampling period (a), and the quantity of years that an individual was seen (b).

During the studied period, new animals were identified every year, but with a higher increase in the last two years (Figure 4.6). Most of the identified individuals were only seen in one year and no animals were sighted in all years of the survey. One can argue that these finding *per si* favor the assumption of an open population.

## 4.3 Site fidelity

From the total of the identified individuals, trough the capture rates, 250 individuals (60,24%) showed a value of site fidelity equal to 0, that means that these individuals were only seen once during the entire survey period. Also, 165 individuals (39,76%) showed site fidelity values under 0.5. These individuals were captured in different years besides the year from their first capture. The values of monthly sighting rates, from all the identified individuals, are under 0.5, indicating that no individual were captured in all the surveyed months.

The low values of Monthly Sighting Rates (MSR) and Capture Rates (CR) obtained suggest that most of the individuals have low probabilities to return to the study area (Table 4.2).

Table 4.2 - Descriptive statistics of Monthly Sighting Rates (MSR) and Capture Rates (CR).

| | **MSR** | **CR** |
|---|---|---|
| Maximum | 0.429 | 0.429 |
| Minimum | 0.036 | 0.006 |
| Mean | 0.059 | 0.028 |

## 4.4 Statistical inference

### 4.4.1 Closed-population models

Figure 4.7 shows the estimations of the population size from each model, during the survey period. The highest estimate of population size was in 2011, reaching a total of 461 individuals with the model $M_0$ and 447 individuals with model $M_h$. The population had the lowest sizes, in the years 2012 and 2013, namely 22 individuals in 2013 under the model $M_t$.

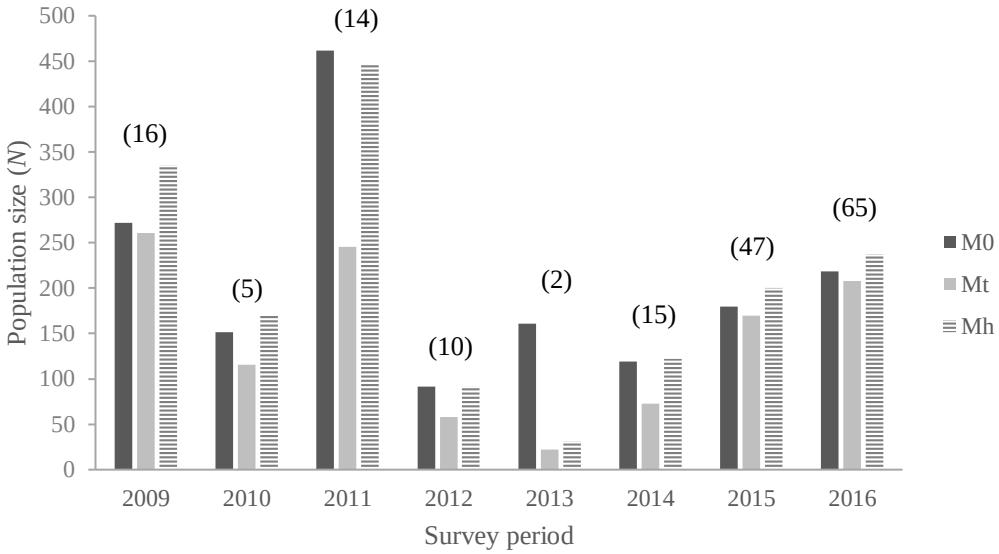


Figure 4.7 – Population size (*N*) variation through all the years, under three different closed-population models, $M_0$, $M_t$ and $M_h$. Number in parenthesis represent number of sampling days.

The model $M_h$ was the one that fitted best to the data because of their lowest DIC values and with ΔDIC equal to 0 in every year.

Table 4.3 - Deviance information criteria (DIC) and differences between model's DIC (ΔDIC), from each model in all years of the survey.

| | 2009 | | 2010 | | 2011 | | 2012 | |
|---|---|---|---|---|---|---|---|---|
| **Model** | **DIC** | **ΔDIC** | **DIC** | **ΔDIC** | **DIC** | **ΔDIC** | **DIC** | **ΔDIC** |
| **$M_0$** | 3232.88 | 1709.34 | 1002.02 | 262.56 | 20442.66 | 610.9 | 663.99 | 240.52 |
| **$M_t$** | 3028.49 | 1504.95 | 825.59 | 86.13 | 1542.43 | 110.68 | 437.14 | 13.66 |
| **$M_h$** | 1523.54 | 0.00 | 739.47 | 0.00 | 1431.76 | 0.00 | 423.48 | 0.00 |

| | 2013 | | 2014 | | 2015 | | 2016 | |
|---|---|---|---|---|---|---|---|---|
| **Model** | **DIC** | **ΔDIC** | **DIC** | **ΔDIC** | **DIC** | **ΔDIC** | **DIC** | **ΔDIC** |
| **$M_0$** | 49.48 | 26.28 | 946.58 | 376.64 | 3148.94 | 2146.91 | 4330.05 | 3115.79 |
| **$M_t$** | 29.32 | 6.12 | 595.58 | 25.64 | 2884.21 | 1882.19 | 4032.91 | 2818.66 |
| **$M_h$** | 23.20 | 0.00 | 569.94 | 0.00 | 1002.02 | 0.00 | 1214.26 | 0.00 |

The values of detection probability, estimated under each model and for every year of sampling, were always under 0.3 (see Annex A).

### 4.2.2 Open-population models

Figures 4.8 and 4.9 show the estimated posterior distributions and posterior means of apparent survival (Φ) and the recapture probability (*p*) under the Cormack-Jolly-Seber (CJS) model, respectively.

The CJS model estimated an apparent survival mean value of 0.789 (95%$C_R$I=0.737-0.843) and a recapture probability mean value of 0.158 (95%$C_R$I=0.124-0.195) (Annex B).

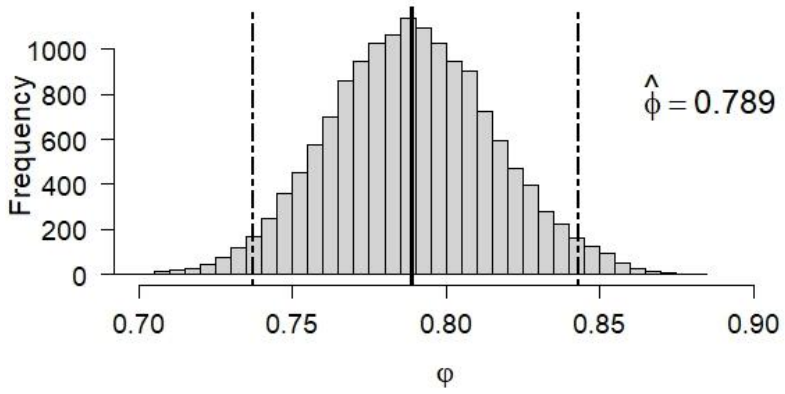


Figure 4.8 – Posterior distribution and estimated mean of apparent survival (Φ) under the Cormack-Jolly-Seber model. The black dotted lines represent the 95% interval of credibility, lower and upper boundaries at 2.5% and 97.5%, respectively.

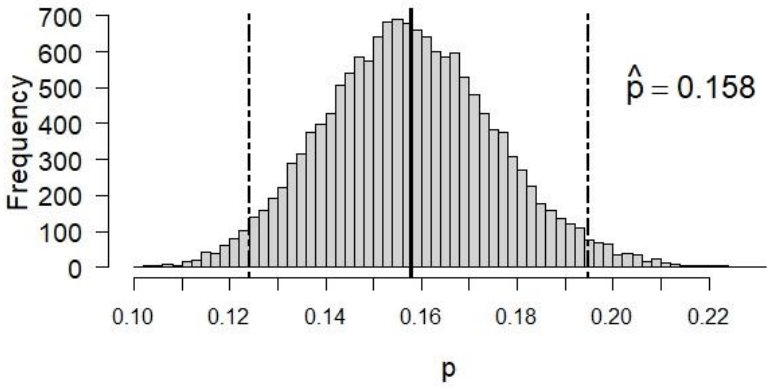


Figure 4.9 – Posterior distribution and estimated mean of probability of recapture (*p*) under the Cormack-Jolly-Seber model. The black dotted lines represent the 95% interval of credibility, lower and upper boundaries at 2.5% and 97.5%, respectively.

The values estimated with the Jolly-Seber (JS) model differ slightly from the ones estimated under with the CJS model. Figure 4.10 and 4.11, shows the posterior distribution and posterior means of probabilities of survival and capture, respectively. The probability of capture during the survey period was 0.311 (95%$C_R$I=0.281-0.342) and the probability of survival was 0.809 (95%$C_R$I=0.504-0.97), with the JS model (Annex B).

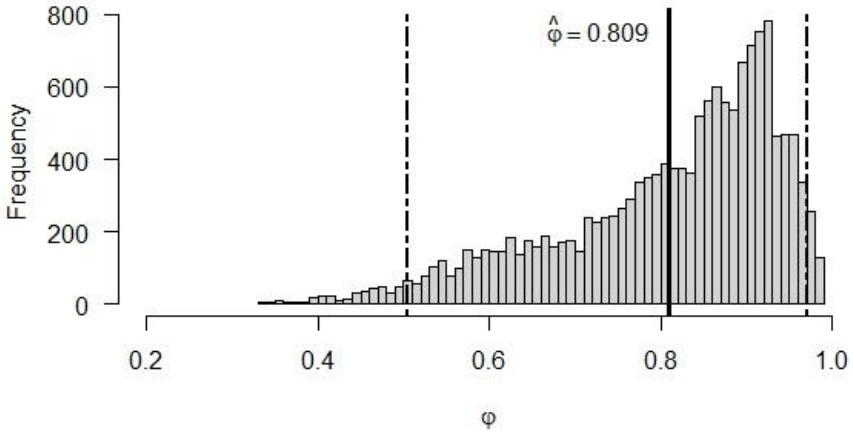


Figure 4.10 – Posterior distribution and estimated mean of survival (Φ) under the Jolly-Seber model. The black dotted lines represent the 95% interval of credibility, lower and upper boundaries at 2.5% and 97.5%, respectively.

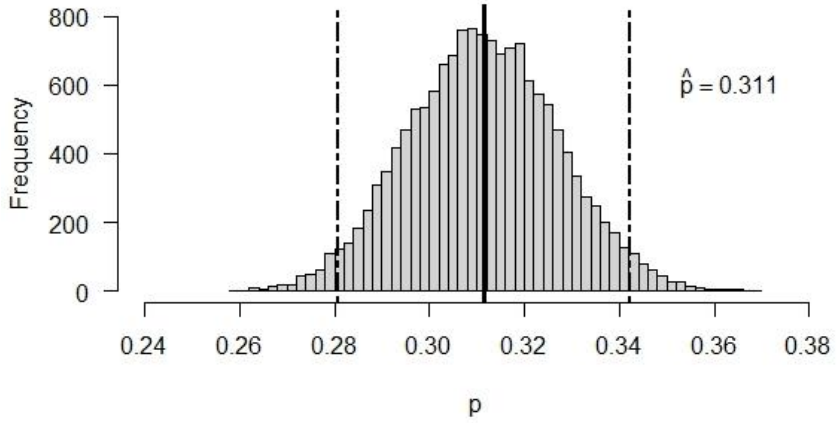


Figure 4.11 – Posterior distribution and estimated mean of probability of capture (*p*) under the Jolly-Seber model. The black dotted lines represent the 95% interval of credibility, lower and upper boundaries at 2.5% and 97.5%, respectively.

Figure 4.12 illustrates the estimated values of population size under JS model during the entire survey period. The population size had some fluctuations during the study period, with the highest value estimated in 2009 (564 individuals; 95%$C_R$I=514-616). Afterwards, it decreased attaining the lowest value in 2013, (88 individuals; 95%$C_R$I=74-106). The population size had an increase in the last two years but did not achieve the maximum value already obtained in 2009 - 357 individuals (95%$C_R$I=303-430) in 2015 and 439 individuals (95%$C_R$I=404-478) in 2016. The superpopulation size estimated, that is the number of individuals alive estimated during the survey in the south of Portugal, was 1038.

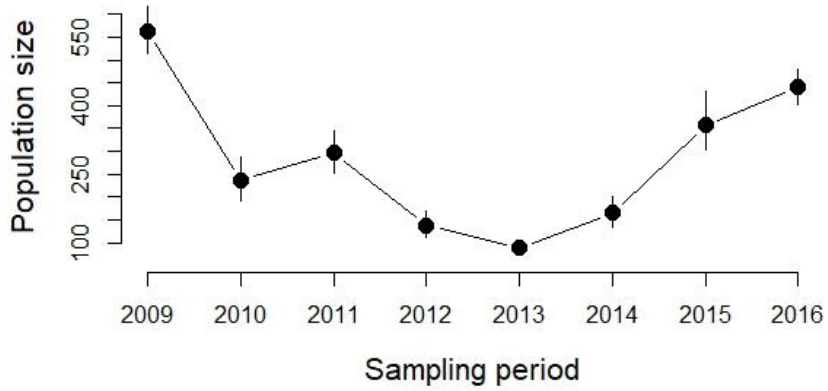


Figure 4.12 - Posterior mean of population size of bottlenose dolphins in the South of Portugal. Vertical lines, in each point, represent the 95% interval of credibility.

Regarding the per capita recruitment, it showed strong temporal fluctuations, with 2010, 2012 and 2013 values very close to 0 (Figure 4.13) (Annex B). The highest probability value for entering new animals to the population was in 2015, which was estimated as 194 animals.

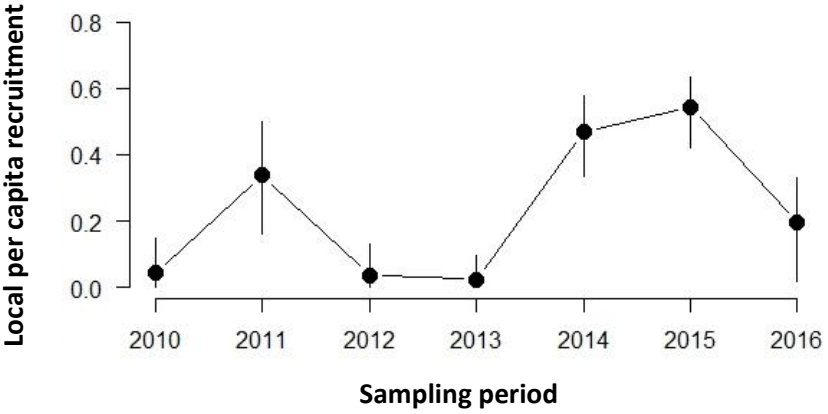


Figure. 4.13 - Posterior mean of per capita recruitment of bottlenose dolphins in the South of Portugal. Vertical lines, in each point, represent the 95% interval of credibility.

# 5. Discussion

Portugal, as a member of European Union, has the responsibility to act accordingly the Habitats Directive, that aims the conservation of habitats and biodiversity. NATURA 2000 network, being a part of Habitats Directive, comprehends areas that are classified as Special Areas of Conservation (SAC), where the main goal is to protect threatened habitats and species in Europe (Ribarič 2017). The bottlenose dolphins are under these jurisdictions and in 2016, the ICNF (Conservation Institute of Nature and Forests) proposed an extension to those protected areas to include zones where higher number of sightings are recorded, the same as those studied here (see Figure 4.5). Within this context, it is important to determine the abundance of bottlenose dolphins on these protected areas, to correctly define them and if they can support the entire population (Parsons 2001).

Here is shown that bottlenose dolphins' distribution in the Portuguese southern coast was concentrated close to shore, with a special incidence in Albufeira area (Figure 4.5), were occurs the highest sampling effort. The high number of bottlenose dolphin sightings in the study area can be related to the presence of multiple submarine canyons (Dinis *et al.* 2016). In fact, submarine canyons are considered to be attractive spots for cetaceans due to increased food availability (e.g. fishes and crustaceans) associated to enhanced upwelling-driven surface productivity (Baumgartner *et al.* 2001; Moors-Murphy 2014). Also, some argue that this species is found closer to shore in warmer months because these areas are important for breeding and calving (Lusseau 2005).

During the sampling period, it was possible to observe a certain number of newborns and calves, and some sexual interactions, which suggest that the dolphins use the study area as a breeding and nursery area. Adding this information to the fact that, in each year of the survey, newly individuals were identified (see Figure 4.6), which makes possible to affirm that the population observed in the study area is an open population (Pollock and Alpizar-Jara 2010).

As mentioned above (in section 1.4), in open coastal habitats, the individuals usually show low site fidelity values towards a specific area (Fury and Harrison 2008). Here, the identified bottlenose dolphins revealed low values of site fidelity (Table 4.2). Therefore, it is possible to state that the dolphins were occasional visitors and that the studied area worked as local of passaged or migratory route. Defran and Weller (1999) also found that bottlenose dolphins in the coastline of San Diego, California, had low fidelity to such area. The same trend was observed by Bouveroux *et al.* (2014) and Dinis *et al.* (2016) in Panama City and Madeira Archipelago, respectively. The latter two studies also showed that most of the identified individuals where only seen once (42% and 78%, respectively). This scenario changes in estuarine habitats and costal protect areas, where the individuals have a high site fidelity. For instance, Vermeulen *et al.* (2016), in central Argentina, revealed that 78% of the individuals, were re-sighted in every study year, showing a strong fidelity to the Bahía San Antonio.

The populations inhabiting these two different habitats, namely costal and estuarine, also usually differ in population size. Those that inhabit open coastal habitats are expected to have higher abundance (Laporta *et al.* 2016) than the ones located in estuarine habitats (Balmer *et al.* 2008).

The abundance of individuals in the present study had fluctuations through the sampling years, considering both closed and open population models. Both type of models estimated the lower population sizes in the years 2012 and 2013. Yet, such models also showed big discrepancies in the population size in some years. For instance, while the closed-population models estimated the

higher number of individuals in 2011, the open-population model Jolly-Seber estimated in 2009. Although it is very important to note that these fluctuations on population size depends on the sampling effort made. To have realistic comparisons between the different sampling years and to obtained realistic conclusions, a standardization in effort should be made.
It is also important to note that the estimation of the demographic parameters only considered the marked individuals of the population. To obtained an estimation of the entire population, it is necessary to account the non-distinctive individuals (Vieira 2017).

The closed-population model $M_h$, that accounts the heterogeneity in the probability of detection among individuals, was the one who fits best (Table 4.3) to the present data. A similar result was obtained by Bouveroux *et al.* (2014) in Panama City, Florida. Under the open-population model and for the year 2016, the population was estimated in 439 individuals. Louis *et al.* (2015), through the analysis of different studies, refers that the size of coast populations of bottlenose dolphins range from around 10 individuals (e.g. population located in Brittany, France) to a maximum of 350 individuals in a population located in Spain. The former study also had estimated that the English Channel bottlenose dolphins' population had 420 individuals. With this context, one can argue that this population in Algarve could be one of the biggest coastal populations of bottlenose dolphins in Europe. Although, a comparison between studies is only possible if all studies have equal sampling efforts. The former assumption can be considered as valid if the sampling effort is not take into consideration.

Adding to the abundance estimation values, other parameters were also determined, namely survival, probability of capture and recruitment. In both open-population models, Cormack-Jolly-Seber and Jolly-Seber, the values of apparent survival and survival, respectively, where high, demonstrating that the observed individuals show a good fitness to the environment. Moreover, recapture probability, under the Cormack-Jolly-Seber model, and capture probabilities, under the Jolly-Seber model, were both low, suggesting that individuals' home range has a much larger extension than the surveyed area. The probability of entering new individuals to the population was never very high. The population maintain mostly the same individuals, with few incomes every year.

The demographic parameters estimated presented in this dissertation, such as abundance, distribution and site fidelity, are known to be influenced by different factors, including prey distribution (McCluskey *et al.* 2016), predation risk (Toth *et al.* 2011), temperature (Baş *et al.* 2016) and habitat characteristics (Martinho *et al.* 2014). Knowing these different demographic parameters about a population is very important to assess effective long-term conservation measures (Bassos-Hull *et al.* 2013; Ribarič 2017) and to limit boundaries for marine protected areas (Culloch and Robinson 2008). Yet, the establishment of correct conservation measures towards cetaceans is quite challenging due their wide home range and their seasonal occurrences (Laran *et al.* 2017).

Most coastal areas are still expanding economically, leading to an increase in tourism activity. Due to the individuals' proximity to the shore they are inherently subject to anthropogenic pressure. This can affect their distribution and abundance (Pleslić *et al.* 2013). Algarve is an important tourism destination and in the last few years, the dolphin-watching market has been greatly increasing, with nowadays, 7 companies only in Albufeira. Pleslić *et al.* (2013) refers that unregulated dolphin-watching operations can induce avoidance, by bottlenose dolphins, in certain areas. This type of disturbance can also elicit sever effects on the individuals' fitness. Constant disturbances can cause critical shifts in the behavior (i.e. feeding, socializing and breeding) that

is crucial for a healthy population (Smith *et al.* 2016). Also, due to the dynamic bottlenose dolphins' fission-fusion society, the disruption of the social bounds, originated by this activity, can have severe repercussions in their future. Bottlenose dolphins' life rely on long-term specific bounds (Bedjer *et al.* 2006).

Other important impact is the extensive exploration in fisheries stocks, that can lead to direct and indirect interactions between fisheries and marine top predators (McCluskey *et al.* 2016). Bottlenose dolphins had the tendency to follow fisheries vessels and that can create a partial dependence on human activity (Gnone *et al.* 2011) and increase the probability of bycatch and ship strikes.

Through a holistic perspective, this study can be considered as relevant in also the protection of other species. Delimiting protection and conservation plans towards the bottlenose dolphins can contribute to the protection of other species that are present in the Portuguese south coast, namely killer whales (*Orcinus orca*), fin whale (*Balaenoptera physalus*) and minke whale (*Balaenoptera acutorostrata*). Also, Hooker and Gerber (2004) suggest that marine top predators, like bottlenose dolphins, are indicator species, that is they can contribute do assess subjacent prey distribution and ecosystem processes. This dissertation is also very important, because it contributed to the addition of a minimum of 300 new individuals to the first catalogue of bottlenose dolphins in the south coast of Portugal. This new catalogue allows a better understanding of these individuals.

Summing up, this dissertation aimed to contribute to the advance on the knowledge of bottlenose dolphins' population in the south of Portugal. In future studies, it would be interesting, for example, to extend the survey periods to the winter months, to fully assess residency and to try to fully understand if the individuals are suffering from the increase of dolphin-watching industry. Also, due to fission-fusion social characteristic of bottlenose dolphins, it would be interesting to evaluate the social structure and associations between individuals. The comparison between the catalogue obtained in the present dissertation and other bottlenose dolphins catalogues, will contribute to acquire a bigger perspective of the real distribution of the bottlenose dolphins present in the south coast of Portugal. For example, in 2009 was made a comparison between the initial catalogue of the individuals present in the south coast of Portugal and the Gulf Cadiz catalogue, where was obtained a correspondence of four individuals.

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# Annex A

The tables present in this Annex correspond to a numerical summary of the posterior distributions of the different parameters estimated in all closed-population tested models. The information about the mean, standard deviation and credible interval of 95%, with lower (LCRI -2.5%) and upper boundaries (UPCRI - 97.5%), are also shown in the tables.

## List of tables



Table A1 – Posterior summaries of $M_0$ model parameters, population size (*N*) and detection probability (*p*), for the bottlenose dolphins data. Is also represented the mean, standard deviations and the 95% interval of credibility,

| | | Estimates | | | |
|---|---|---|---|---|---|
| | | | | 95 % CRI | |
| **Year** | **Parameters** | **Mean** | **Standard Deviation** | **LCRI** | **UPCRI** |
| | N | 271,69 | 13,13 | 248 | 300 |
| | *p* | 0,079 | 0,006 | 0,069 | 0,09 |
| 2009 | Deviance | 2548,27 | 36,49 | 2479 | 2623 |
| | N | 151,154 | 41,545 | 95 | 248 |
| | *p* | 0,097 | 0,026 | 0,052 | 0,152 |
| 2010 | Deviance | 453,321 | 35,539 | 390,8 | 529 |
| | N | 461,761 | 97,821 | 285 | 655 |
| | *p* | 0,016 | 0,004 | 0,01 | 0,026 |
| 2011 | Deviance | 1028,469 | 44,221 | 935,4 | 1104 |
| | N | 91,219 | 29,167 | 55 | 168,025 |
| | *p* | 0,056 | 0,017 | 0,026 | 0,092 |
| 2012 | Deviance | 361,242 | 27,061 | 316,7 | 422,805 |
| | N | 160,586 | 274,491 | 2 | 1051 |
| | *p* | 0,104 | 0,155 | 0,001 | 0,572 |
| 2013 | Deviance | 19,67 | 7,676 | 5,812 | 33,24 |
| | N | 118,816 | 29,991 | 76,975 | 192 |
| | *p* | 0,036 | 0,009 | 0,02 | 0,056 |
| 2014 | Deviance | 522,31 | 28,94 | 471,9 | 584,5 |
| | N | 179,505 | 7,116 | 167 | 195 |
| | *p* | 0,039 | 0,003 | 0,035 | 0,045 |
| 2015 | Deviance | 2793,027 | 26,589 | 2744 | 2849 |
| | N | 218,493 | 6,936 | 206 | 233 |
| 2016 | *p* | 0,031 | 0,002 | 0,028 | 0,035 |

| | | | | | |
|---|---|---|---|---|---|
| | Deviance | 3924,237 | 28,32 | 3872 | 3984 |

Table A2 – Posterior summaries of $M_t$ model parameters, population size (*N*) and detection probability (*p*), for the bottlenose dolphins data. Each year has different detection probabilities which correspond to different sampling occasions.

| | | **Estimates** | | | |
|---|---|---|---|---|---|
| | | | | **95 % CRI** | |
| **Year** | **Parameters** | **Mean** | **Standard Deviation** | **LCRI** | **UPCRI** |
| 2009 | N | 260,45 | 11,673 | 240 | 285 |
| | *p[1]* | 0,1 | 0,019 | 0,066 | 0,14 |
| | *p[2]* | 0,038 | 0,012 | 0,019 | 0,064 |
| | *p[3]* | 0,099 | 0,019 | 0,064 | 0,112 |
| | *p[4]* | 0,111 | 0,02 | 0,075 | 0,153 |
| | *p[5]* | 0,004 | 0,004 | 0,005 | 0,014 |
| | *p[6]* | 0,099 | 0,019 | 0,064 | 0,138 |
| | *p[7]* | 0,065 | 0,015 | 0,038 | 0,098 |
| | *p[8]* | 0,076 | 0,016 | 0,047 | 0,111 |
| | *p[9]* | 0,064 | 0,015 | 0,038 | 0,098 |
| | *p[10]* | 0,069 | 0,016 | 0,042 | 0,103 |
| | *p[11]* | 0,046 | 0,013 | 0,023 | 0,075 |
| | *p[12]* | 0,088 | 0,018 | 0,056 | 0,125 |
| | *p[13]* | 0,149 | 0,023 | 0,107 | 0,195 |
| | *p[14]* | 0,088 | 0,018 | 0,055 | 0,126 |
| | *p[15]* | 0,183 | 0,026 | 0,136 | 0,236 |
| | *p[16]* | 0,126 | 0,021 | 0,088 | 0,171 |
| | *p[17]* | 0,05 | 0,014 | 0,027 | 0,079 |
| | Deviance | 2416,178 | 34,989 | 2353 | 2487 |
| 2010 | N | 115,283 | 24,398 | 82 | 176 |
| | *p[1]* | 0,062 | 0,026 | 0,023 | 0,123 |
| | *p[2]* | 0,036 | 0,019 | 0,009 | 0,082 |
| | *p[3]* | 0,23 | 0,058 | 0,129 | 0,352 |
| | *p[4]* | 0,142 | 0,042 | 0,072 | 0,235 |
| | *p[5]* | 0,177 | 0,049 | 0,095 | 0,281 |
| | Deviance | 389,618 | 29,572 | 339,7 | 454,9 |
| 2011 | N | 245,328 | 44,976 | 174 | 348 |
| | *p[1]* | 0,025 | 0,011 | 0,009 | 0,052 |
| | *p[2]* | 0,012 | 0,007 | 0,002 | 0,031 |
| | *p[3]* | 0,079 | 0,022 | 0,043 | 0,128 |
| | *p[4]* | 0,008 | 0,006 | 0,001 | 0,024 |
| | *p[5]* | 0,025 | 0,011 | 0,008 | 0,051 |
| | *p[6]* | 0,021 | 0,01 | 0,006 | 0,045 |
| | *p[7]* | 0,033 | 0,013 | 0,013 | 0,063 |
| | *p[8]* | 0,037 | 0,014 | 0,016 | 0,071 |
| | *p[9]* | 0,025 | 0,011 | 0,009 | 0,05 |
| | *p[10]* | 0,084 | 0,023 | 0,045 | 0,135 |
| | *p[11]* | 0,029 | 0,012 | 0,011 | 0,057 |

| | | | | | |
|---|---|---|---|---|---|
| | *p[12]* | 0,017 | 0,009 | 0,004 | 0,037 |
| | *p[13]* | 0,042 | 0,015 | 0,018 | 0,077 |
| | *p[14]* | 0,039 | 0,014 | 0,015 | 0,07 |
| | Deviance | 867,527 | 36,779 | 800,047 | 943,205 |
| 2012 | N | 58,072 | 9,714 | 44 | 81 |
| | *p[1]* | 0,034 | 0,025 | 0,004 | 0,097 |
| | *p[2]* | 0,12 | 0,047 | 0,047 | 0,227 |
| | *p[3]* | 0,102 | 0,043 | 0,038 | 0,203 |
| | *p[4]* | 0,136 | 0,049 | 0,058 | 0,247 |
| | *p[5]* | 0,034 | 0,024 | 0,004 | 0,096 |
| | *p[6]* | 0,101 | 0,042 | 0,037 | 0,197 |
| | *p[7]* | 0,153 | 0,052 | 0,068 | 0,268 |
| | *p[8]* | 0,171 | 0,055 | 0,08 | 0,291 |
| | *p[9]* | 0,187 | 0,017 | 0,001 | 0,063 |
| | *p[10]* | 0,085 | 0,039 | 0,027 | 0,177 |
| | Deviance | 305,244 | 16,254 | 276,9 | 340,202 |
| 2013 | N | 22,223 | 74,272 | 2 | 145,025 |
| | *p[1]* | 0,278 | 0,224 | 0,007 | 0,804 |
| | *p[2]* | 0,277 | 0,222 | 0,006 | 0,793 |
| | Deviance | 12,902 | 5,817 | 5,689 | 27,37 |
| 2014 | N | 72,754 | 10,238 | 57 | 96 |
| | *p[1]* | 0,027 | 0,019 | 0,003 | 0,077 |
| | *p[2]* | 0,041 | 0,024 | 0,009 | 0,098 |
| | *p[3]* | 0,041 | 0,024 | 0,008 | 0,099 |
| | *p[4]* | 0,081 | 0,033 | 0,03 | 0,155 |
| | *p[5]* | 0,027 | 0,02 | 0,003 | 0,078 |
| | *p[6]* | 0,069 | 0,032 | 0,022 | 0,144 |
| | *p[7]* | 0,014 | 0,014 | 0 | 0,053 |
| | *p[8]* | 0,108 | 0,039 | 0,045 | 0,198 |
| | *p[9]* | 0,027 | 0,019 | 0,003 | 0,076 |
| | *p[10]* | 0,204 | 0,054 | 0,111 | 0,322 |
| | *p[11]* | 0,108 | 0,039 | 0,046 | 0,193 |
| | *p[12]* | 0,067 | 0,03 | 0,22 | 0,136 |
| | *p[13]* | 0,041 | 0,024 | 0,009 | 0,101 |
| | *p[14]* | 0,068 | 0,031 | 0,022 | 0,14 |
| | *p[15]* | 0,096 | 0,036 | 0,04 | 0,179 |
| | Deviance | 436,209 | 17,893 | 404,6 | 474,802 |
| 2015 | N | 169,377 | 5,095 | 160 | 180 |
| | *p[1]* | 0,029 | 0,031 | 0,01 | 0,059 |
| | *p[2]* | 0,023 | 0,012 | 0,007 | 0,051 |
| | *p[3]* | 0,012 | 0,008 | 0,001 | 0,032 |
| | *p[4]* | 0,047 | 0,016 | 0,02 | 0,083 |
| | *p[5]* | 0,076 | 0,02 | 0,041 | 0,12 |
| | *p[6]* | 0,029 | 0,013 | 0,009 | 0,06 |

| | | | | | |
|---|---|---|---|---|---|
| | *p[7]* | 0,018 | 0,01 | 0,004 | 0,041 |
| | *p[8]* | 0,023 | 0,011 | 0,006 | 0,049 |
| | *p[9]* | 0,006 | 0,006 | 0 | 0,021 |
| | *p[10]* | 0,07 | 0,02 | 0,037 | 0,112 |
| | *p[11]* | 0,017 | 0,01 | 0,003 | 0,043 |
| | *p[12]* | 0,052 | 0,017 | 0,024 | 0,091 |
| | *p[13]* | 0,064 | 0,019 | 0,033 | 0,106 |
| | *p[14]* | 0,029 | 0,013 | 0,01 | 0,059 |
| | *p[15]* | 0,023 | 0,012 | 0,006 | 0,051 |
| | *p[16]* | 0,093 | 0,023 | 0,055 | 0,142 |
| | *p[17]* | 0,047 | 0,016 | 0,021 | 0,084 |
| | *p[18]* | 0,041 | 0,015 | 0,017 | 0,075 |
| | *p[19]* | 0,058 | 0,018 | 0,029 | 0,098 |
| | *p[20]* | 0,07 | 0,019 | 0,037 | 0,112 |
| | *p[21]* | 0,012 | 0,008 | 0,002 | 0,032 |
| | *p[22]* | 0,099 | 0,023 | 0,059 | 0,148 |
| | *p[23]* | 0,018 | 0,01 | 0,004 | 0,042 |
| | *p[24]* | 0,012 | 0,008 | 0,001 | 0,033 |
| | *p[25]* | 0,052 | 0,017 | 0,024 | 0,09 |
| 2015 | *p[26]* | 0,041 | 0,015 | 0,017 | 0,075 |
| | *p[27]* | 0,018 | 0,01 | 0,004 | 0,042 |
| | *p[28]* | 0,047 | 0,016 | 0,021 | 0,083 |
| | *p[29]* | 0,07 | 0,019 | 0,037 | 0,113 |
| | *p[30]* | 0,041 | 0,015 | 0,017 | 0,076 |
| | *p[31]* | 0,035 | 0,014 | 0,013 | 0,067 |
| | *p[32]* | 0,105 | 0,023 | 0,065 | 0,155 |
| | *p[33]* | 0,088 | 0,021 | 0,05 | 0,134 |
| | *p[34]* | 0,041 | 0,015 | 0,016 | 0,075 |
| | *p[35]* | 0,023 | 0,012 | 0,006 | 0,051 |
| | *p[36]* | 0,017 | 0,01 | 0,004 | 0,042 |
| | *p[37]* | 0,105 | 0,023 | 0,064 | 0,155 |
| | *p[38]* | 0,058 | 0,018 | 0,029 | 0,098 |
| | *p[39]* | 0,07 | 0,02 | 40,037 | 0,115 |
| | *p[40]* | 0,128 | 0,026 | 0,082 | 0,182 |
| | *p[41]* | 0,023 | 0,012 | 0,007 | 0,051 |
| | *p[42]* | 0,058 | 0,017 | 0,028 | 0,096 |
| | *p[43]* | 0,024 | 0,012 | 0,007 | 0,052 |
| | *p[44]* | 0,012 | 0,009 | 0,001 | 0,033 |
| | *p[45]* | 0,071 | 0,02 | 0,037 | 0,113 |
| | *p[46]* | 0,058 | 0,018 | 0,029 | 0,098 |
| | *p[47]* | 0,052 | 0,017 | 0,024 | 0,089 |
| | Deviance | 2625,073 | 22,768 | 2584 | 2672 |
| | N | 207,603 | 5,019 | 199 | 218 |
| 2016 | *p[1]* | 0,095 | 0,02 | 0,059 | 0,139 |
| | *p[2]* | 0,048 | 0,015 | 0,023 | 0,079 |
| | *p[3]* | 0,014 | 0,008 | 0,003 | 0,034 |

| | | | | | |
|---|---|---|---|---|---|
| | *p[4]* | 0,038 | 0,013 | 0,016 | 0,067 |
| | *p[5]* | 0,009 | 0,007 | 0,001 | 0,026 |
| | *p[6]* | 0,017 | 0,018 | 0,04 | 0,11 |
| | *p[7]* | 0,038 | 0,013 | 0,017 | 0,068 |
| | *p[8]* | 0,019 | 0,01 | 0,005 | 0,043 |
| | *p[9]* | 0,062 | 0,017 | 0,034 | 0,099 |
| | *p[10]* | 0,053 | 0,016 | 0,026 | 0,087 |
| | *p[11]* | 0,09 | 0,02 | 0,056 | 0,132 |
| | *p[12]* | 0,019 | 0,009 | 0,005 | 0,041 |
| | *p[13]* | 0,076 | 0,018 | 0,044 | 0,115 |
| | *p[14]* | 0,029 | 0,011 | 0,011 | 0,055 |
| | *p[15]* | 0,014 | 0,008 | 0,003 | 0,035 |
| | *p[16]* | 0,091 | 0,02 | 0,057 | 0,134 |
| | *p[17]* | 0,057 | 0,016 | 0,03 | 0,093 |
| | *p[18]* | 0,01 | 0,007 | 0,001 | 0,027 |
| | *p[19]* | 0,009 | 0,007 | 0,001 | 0,026 |
| | *p[20]* | 0,052 | 0,015 | 0,027 | 0,086 |
| | *p[21]* | 0,019 | 0,009 | 0,005 | 0,041 |
| | *p[22]* | 0,014 | 0,008 | 0,003 | 0,033 |
| 2016 | *p[23]* | 0,038 | 0,013 | 0,017 | 0,068 |
| | *p[24]* | 0,086 | 0,02 | 0,052 | 0,129 |
| | *p[25]* | 0,019 | 0,009 | 0,005 | 0,042 |
| | *p[26]* | 0,038 | 0,013 | 0,017 | 0,067 |
| | *p[27]* | 0,072 | 0,018 | 0,041 | 0,11 |
| | *p[28]* | 0,015 | 0,008 | 0,003 | 0,035 |
| | *p[29]* | 0,024 | 0,011 | 0,008 | 0,049 |
| | *p[30]* | 0,009 | 0,006 | 0,001 | 0,026 |
| | *p[31]* | 0,019 | 0,009 | 0,005 | 0,042 |
| | *p[32]* | 0,057 | 0,016 | 0,03 | 0,093 |
| | *p[33]* | 0,029 | 0,012 | 0,01 | 0,055 |
| | *p[34]* | 0,024 | 0,011 | 0,008 | 0,049 |
| | *p[35]* | 0,058 | 0,016 | 0,03 | 0,093 |
| | *p[36]* | 0,033 | 0,012 | 0,014 | 0,061 |
| | *p[37]* | 0,038 | 0,013 | 0,016 | 0,068 |
| | *p[38]* | 0,029 | 0,012 | 0,011 | 0,055 |
| | *p[39]* | 0,034 | 0,013 | 0,014 | 0,061 |
| | *p[40]* | 0,024 | 0,011 | 0,008 | 0,048 |
| | *p[41]* | 0,029 | 0,012 | 0,01 | 0,055 |
| | *p[42]* | 0,043 | 0,014 | 0,02 | 0,075 |
| | *p[43]* | 0,038 | 0,013 | 0,016 | 0,068 |
| | *p[44]* | 0,019 | 0,009 | 0,005 | 0,041 |
| | *p[45]* | 0,014 | 0,008 | 0,003 | 0,034 |
| | *p[46]* | 0,033 | 0,012 | 0,013 | 0,061 |

| | | | | | |
|---|---|---|---|---|---|
| | *p[47]* | 0,072 | 0,018 | 0,041 | 0,11 |
| | *p[48]* | 0,024 | 0,011 | 0,008 | 0,049 |
| | *p[49]* | 0,048 | 0,015 | 0,023 | 0,081 |
| | *p[50]* | 0,009 | 0,007 | 0,001 | 0,026 |
| | *p[51]* | 0,014 | 0,008 | 0,003 | 0,034 |
| | *p[52]* | 0,034 | 0,012 | 0,014 | 0,062 |
| | *p[53]* | 0,038 | 0,018 | 0,017 | 0,068 |
| | *p[54]* | 0,019 | 0,011 | 0,005 | 0,041 |
| | *p[55]* | 0,014 | 0,015 | 0,003 | 0,034 |
| | *p[56]* | 0,043 | 0,007 | 0,02 | 0,075 |
| 2016 | *p[57]* | 0,033 | 0,008 | 0,014 | 0,062 |
| | *p[58]* | 0,014 | 0,012 | 0,003 | 0,034 |
| | *p[59]* | 0,038 | 0,013 | 0,016 | 0,067 |
| | *p[60]* | 0,033 | 0,02 | 0,014 | 0,062 |
| | *p[61]* | 0,086 | 0,013 | 0,052 | 0,129 |
| | *p[62]* | 0,038 | 0,014 | 0,017 | 0,068 |
| | *p[63]* | 0,043 | 0,012 | 0,02 | 0,075 |
| | *p[64]* | 0,029 | 0,012 | 0,011 | 0,055 |
| | *p[65]* | 0,029 | 0,019 | 0,011 | 0,056 |
| | Deviance | 3732,452 | 24,518 | 3687 | 3783 |

Table A3 – Posterior summaries of $M_h$ model parameters, population size (*N*) and detection probability (*p*), for the bottlenose dolphins data.

| | | Estimates | | | |
|---|---|---|---|---|---|
| | | | | 95 % CRI | |
| **Year** | **Parameters** | **Mean** | **Standard Deviation** | **LCRI** | **UPCRI** |
| 2009 | N | 339,846 | 22,784 | 298 | 387 |
| | *p* | 0,053 | 0,005 | 0,044 | 0,064 |
| | sd | 0,692 | 0,058 | 0,569 | 0,798 |
| | Deviance | 829,046 | 37,239 | 759,3 | 905,4 |
| 2010 | N | 170,955 | 12,804 | 110 | 273 |
| | *p* | 0,08 | 0,021 | 0,044 | 0,121 |
| | sd | 0,349 | 0,217 | 0,012 | 0,736 |
| | Deviance | 266,471 | 32,365 | 208,8 | 334 |
| 2011 | N | 447,168 | 102,749 | 292 | 678 |
| | *p* | 0,017 | 0,004 | 0,011 | 0,025 |
| | sd | 0,126 | 0,087 | 0,004 | 0,313 |
| | Deviance | 505,668 | 45,974 | 424,4 | 595,802 |
| 2012 | N | 91,686 | 24,731 | 58 | 150 |
| | *p* | 0,052 | 0,014 | 0,029 | 0,083 |
| | sd | 0,353 | 0,158 | 0,085 | 0,647 |
| | Deviance | 164,437 | 22,818 | 125,5 | 213,9 |
| 2013 | N | 31,172 | 43,988 | 2 | 160 |
| | *p* | 0,15 | 0,163 | 0,012 | 0,638 |
| | sd | 0,13 | 0,277 | 0,012 | 0,949 |
| | Deviance | 12,721 | 5,927 | 5,927 | 24,99 |
| 2014 | N | 122,108 | 25,57 | 83 | 181 |
| | *p* | 0,033 | 0,007 | 0,021 | 0,05 |
| | sd | 0,312 | 0,138 | 0,051 | 0,554 |
| | Deviance | 220,875 | 25,305 | 175,5 | 273,5 |
| 2015 | N | 200,024 | 9,887 | 182 | 221 |
| | *p* | 0,032 | 0,002 | 0,028 | 0,037 |
| | sd | 0,531 | 0,045 | 0,44 | 0,617 |
| | Deviance | 606,576 | 28,084 | 554,4 | 664 |
| 2016 | N | 237,164 | 9,04 | 221 | 256 |
| | *p* | 0,026 | 0,002 | 0,024 | 0,03 |
| | sd | 0,491 | 0,037 | 0,416 | 0,563 |
| | Deviance | 760,949 | 29,809 | 705,5 | 822,802 |

# Annex B

The tables present in this Annex correspond to a numerical summary of the posterior distributions of the different parameters estimated in both open-population models. The information about the mean, standard deviation and credible interval of 95% are also shown in the tables.

## List of tables



Table B1 – Posterior summaries of Cormack-Jolly-Seber model parameters, apparent survival (Φ) and probability of recapture (*p*), for the bottlenose dolphins data.

| | | **Estimates** | | | |
|---|---|---|---|---|---|
| | | | | **95 % CRI** | |
| **Model** | **Parameters** | **Mean** | **Standard Deviation** | **LCRI** | **UPCRI** |
| Cormack-Jolly-Seber | Φ | 0,789 | 0,027 | 0,737 | 0,843 |
| | *p* | 0,158 | 0,018 | 0,124 | 0,195 |
| | Deviance | 899,161 | 31,514 | 840,7 | 964,1 |

Table B2 - Posterior summaries of Jolly-Seber model parameters, capture (p), survival (Φ), number of individuals alive at each year (N), the number of individuals alive during the study (Nsuper), the probability of entry at each year (b) and the number of individuals entering the population each year (B), for bottlenose dolphins data.

| | | Estimates | | | |
|---|---|---|---|---|---|
| | | | | 95 % CRI | |
| **Model** | **Parameters** | **Mean** | **Standard Deviation** | **LCRI** | **UPCRI** |
| Jolly-Seber | p | 0,311 | 0,016 | 0,281 | 0,342 |
| | Φ | 0,809 | 0,129 | 0,504 | 0,97 |
| | $N_{2009}$ | 563,898 | 26,085 | 514,975 | 616 |
| | $N_{2010}$ | 235,691 | 23,884 | 193 | 287 |
| | $N_{2011}$ | 296,305 | 24,015 | 253 | 345 |
| | $N_{2012}$ | 136,99 | 14,458 | 112 | 168 |
| | $N_{2013}$ | 88,633 | 8,487 | 74 | 106 |
| | $N_{2014}$ | 165,212 | 16,818 | 135 | 201 |
| | $N_{2015}$ | 357,369 | 31,94 | 303,975 | 430 |
| | $N_{2016}$ | 439,392 | 18,656 | 404 | 478 |
| | $N_{super}$ | 1038,831 | 9,352 | 1014 | 1048 |
| | $b_{2009}$ | 0,543 | 0,029 | 0,488 | 0,6 |
| | $b_{2010}$ | 0,011 | 0,01 | 0 | 0,037 |
| | $b_{2011}$ | 0,096 | 0,025 | 0,045 | 0,144 |
| | $b_{2012}$ | 0,006 | 0,005 | 0 | 0,019 |
| | $b_{2013}$ | 0,003 | 0,003 | 0 | 0,011 |
| | $b_{2014}$ | 0,075 | 0,018 | 0,043 | 0,112 |
| | $b_{2015}$ | 0,185 | 0,032 | 0,126 | 0,254 |
| | $b_{2016}$ | 0,082 | 0,034 | 0,008 | 0,146 |
| | $B_{2009}$ | 563,898 | 26,085 | 514,975 | 616 |
| | $B_{2010}$ | 10,15 | 9,824 | 0 | 36 |
| | $B_{2011}$ | 99,153 | 24,027 | 49 | 145 |
| | $B_{2012}$ | 4,935 | 4,948 | 0 | 18 |
| | $B_{2013}$ | 2,155 | 2,656 | 0 | 9 |
| | $B_{2014}$ | 77,771 | 16,42 | 48 | 112 |
| | $B_{2015}$ | 194,288 | 32,167 | 135 | 265 |
| | $B_{2016}$ | 86,482 | 35,115 | 8,975 | 150 |
| | Deviance | 2830,195 | 67,183 | 2704 | 2968 |